ARTIFICIAL REEF CONSTRUCTION: AN ENGINEERED APPROACH

Timothy K. Blankenship, P.E.
R. Harvey Sasso, P.E.

Coastal Systems International, Inc.
464 South Dixie Highway
Coral Gables, Florida 33146

Stephen Higgins
Kenneth Banks

Broward County Department of Planning & Environmental Protection
218 S.W 1st Ave.
Ft. Lauderdale, FL 33301

ABSTRACT

Mitigation for hardbottom impacts is a complicated, costly component of a beach nourishment project. After beach nourishment project impacts have been avoided and minimized to the greatest extent possible, regulatory permits generally require mitigation of hardbottom impacts from the fully equilibrated beach profile by constructing artificial reefs. These mitigation sites are typically required to be placed as close as possible to the impact areas. Therefore, artificial reef construction in the nearshore zone requires innovative construction methodologies due to the proximity of sensitive hardbottom marine resources and shallow water.

The Broward County (Segment III) Shore Protection Project is predicted to impact 7.6 acres of nearshore hardbottom habitat. Regulatory agencies required 10.1 gross acres of artificial reef mitigation in the form of limerock boulders placed between existing reefs in 15-foot water depths at three sites in the vicinity of the beach fill. The project was constructed from June through September 2003, and involved the precise placement of approximately 66,000 tons of 4 to 6 foot diameter (nominal) limestone

boulders acquired from a quarry on Grand Bahama Island.

Due to the construction in narrow, environmentally sensitive areas, a design-build approach was used by the contractor to plan and implement the project. Components of the construction consisted of an innovative pile-based crane barge mooring system designed to efficiently operate in between hardbottom areas in shallow water and not impact marine resources with cables and/or anchors. Underwater video mapping techniques were utilized to confirm sandy bottom conditions for boulder placement and to monitor construction operations. Precise DGPS positioning equipment and software was employed to control boulder placement by the crane. This approach to artificial reef construction ensured the mitigation project was completed on schedule with no impacts to adjacent hardbottom resources.

INTRODUCTION

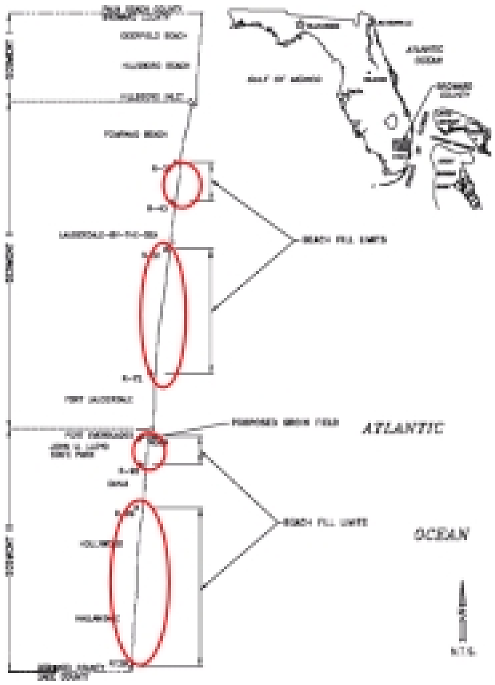
The Broward County (County) Beach Restoration Project is planned to place 2.5 million cubic yards (cy) of sand on approximately 11.8 miles of shoreline. The resulting widened beaches are expected to bury approximately 13.5 acres of nearshore hardbottom during equilibrium of the beach fill. The hardbottom substrate provides habitat for many benthic and fish communities, despite the shallow water and dynamic wave environment. Mitigation of these unavoidable impacts was required.

The Broward County Beach Restoration Project is divided into three segments as follows in Table 1 and as illustrated in Figure 1.

Table 1 - Beach Restoration Project Segments

Segment	Location
I	Palm Beach County Line south to Hillsboro Inlet
II	Hillsboro Inlet south to Port Everglades Inlet
III	Port Everglades Inlet to Miami-Dade County line

Figure 1: Limits of beach restoration, Broward County, Florida.



Construction of the Segment III Beach Restoration was prioritized with construction planned for the summer of 2004. The monitoring and performance of the Segment III mitigation project is a requirement prior to the issuance of environmental permits for construction of Segment II.

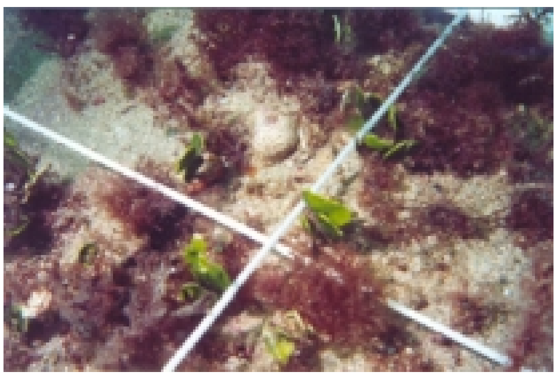
The nearshore reef is generally characterized by low topographic relief, and the marine resources are of lower biological diversity and density as opposed to the offshore reefs in Broward County. Mitigation for these impacts is required to be constructed as close as possible to the impact areas. The mitigation reefs were to be constructed by September, 2003, followed by coral transplantation from the predicted impact nearshore reefs. This program schedule, negotiated over two years with federal and state regulatory and resource agencies, ensures that the mitigation would be in place and functioning prior to the construction of Segment III Beach Restoration.

MITIGATION

Mitigation Requirement

The Segment II and III Beach Restoration projects require the construction of 11.9 acres of substrate within a permitted 13.5 acre footprint. Specifically for Segment III, 10.1 acres were required to compensate for 7.6 acres of predicted impacts. The requirement is based on a 1.2:1 mitigation ratio. The Segment III mitigation was prioritized for initial construction, with Segment II mitigation to follow at a later date.

Figure 2: Mitigation requirement for nearshore impacts.



Limestone boulders were specified in order to provide a substrate suitable as mitigation since the variable relief of local nearshore hardbottom is difficult to replicate. Boulders ranging from 4 feet to 6 feet were analyzed for stability in the nearshore wave environment, and allow for predicted settlement in sandy bottoms adjacent to hard bottom areas. The selected sandy bottom areas consisted of approximately 3 feet of sand over hardbottom to prevent excessive scour or settlement. The distribution of limestone boulders will provide a rugosity of 1.56, which represents a 44% increase in mitigation reef rugosity over natural nearshore hard bottom.

Mitigation Construction Constraints

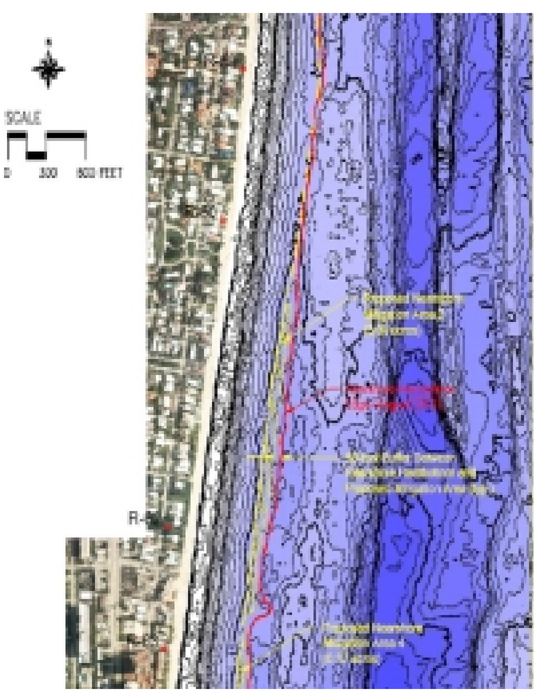
The County permitted 5 sites as follows for Segment III mitigation:

Table 2 - Proposed sites for Segment III Mitigation

Site	Acreage
7	2.97
8	0.67
9	0.33
10	1.86
11	5.70
Total:	11.53

Due to the proximity of the marine resources and nearshore hardbottom, the County required a 50-foot buffer between the mitigation areas and adjacent hardbottom. Furthermore, construction operations over offshore reefs and the shallow water (15 feet) in the mitigation construction areas as shown in Figure 3 presented significant challenges for marine construction.

Figure 3: Mitigation construction areas.



CONSTRUCTION

Contractor Selection

The County procured the mitigation construction through a qualifications-based selection process as opposed to advertising for bids. A Request for Proposals (RFP) was advertised, and contractors were "short-listed." Contractors presented means and methods to complete the construction based on the constraints and schedule established for the project. The County was especially concerned about marine construction in close proximity to nearshore hardbottom and impacts to resources during past mitigation projects in Florida. Coastal Systems Development (CSD) based in Coral Gables, Florida was selected, and a contract to place 66,000 tons of limestone boulders over 10.1 acres of mitigation areas was negotiated for $6M.

Construction Operational Plans

Prior to mobilization, Coastal Systems International, Inc. (CSI) conducted towed underwater video mapping in the Spring of 2003 of the 5 mitigation sites to confirm the proposed construction footprints. The tow vehicle is positioned with DGPS in real time from navigation software to provide project horizontal coordinates on the video feed. The application of this technology provided precise limits of the nearshore hardbottom for mapping as shown in Figure 4 utilizing the County's LADS data as a base map.

Figure 4: Towed underwater video mapping transects.

After the onsite hardbottom edge mapping effort, the updated limits of the hardbottom were overlaid with the proposed mitigation areas, and it became apparent that there was a shortage of available acreage within the permitted mitigation areas for Segment III. The dynamic nature (movement of sand) of the nearshore hardbottom habitat in conjunction with the 50-foot required buffer reduced the available acreage. Additional area was available offshore of Segment II beaches north of Port Everglades, however it was preferable that mitigation be located adjacent to the areas of impact.

Additional towed underwater video mapping conducted by CSI located suitable mitigation areas adjacent to Areas 7 and 11. Jet probes were conducted to confirm the depth of sand in these new areas for compliance with the mitigation requirements. Modifications to the environmental permits were submitted for the revised areas prior to construction.

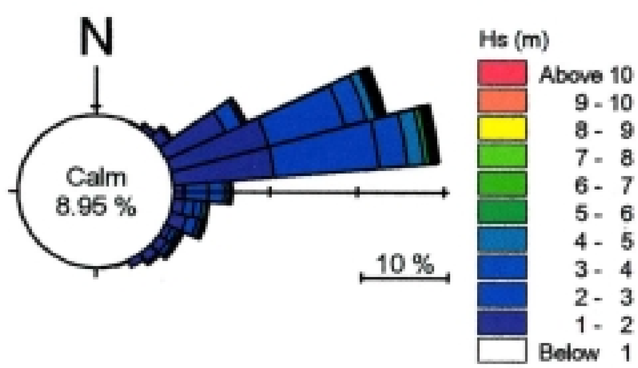
Construction operational plans were prepared to combine Mitigation Areas 7 and 8 and Areas 10 and 11 into two main construction areas along with the additional mitigation areas mapped. Access corridors were mapped, and all coordinate geometry was established for project construction. The plans included details for the crane barge mooring, a temporary single-point-mooring (SPM), ingress and egress corridors, and the locations of reef areas. The plans were submitted to the County for review and approval prior to construction.

ENGINEERING APPROACH

Coastal Engineering

Marine construction in the shallow-water nearshore zones requires careful planning for scheduling of the construction and selection of the equipment profile. Wave Information Study (WIS) statistics were reviewed for the project site prior to construction, and a statistical analysis was performed. The analysis provided wave characteristics (height, period, direction) in the form of exceedance probability tables to determine optimum months for acceptable wave conditions for construction. This combination of coastal engineering along with local marine construction experience indicated that optimum construction period was from mid-May through mid-September (summer months). Conventional floating barge equipment could be utilized to meet the production schedule, although 24-hour/7 days a week construction was required to complete the construction based on estimated production rates and the large quantity of boulders to be placed. The coastal engineering analysis was also used to provide design wave characteristics for both the crane barge mooring system and offshore SPM for temporary supply barge mooring.

Figure 5: Monthly wave statistics.



Mooring Design

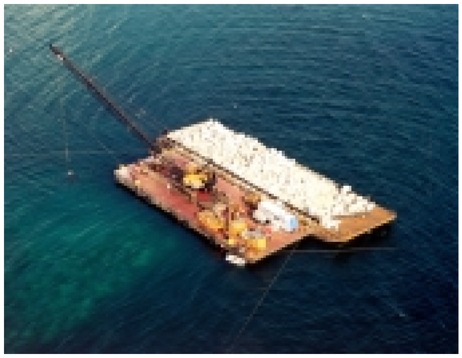
Moorings were designed for both the crane barge that would be used for placing boulders as well as the temporary single-point mooring (SPM) used for the storage of loaded/unloaded barges. The mooring design took into account following construction operational issues:

- Provide safe mooring during normal construction operations
- Use of available mooring hardware, chains, cables, and anchors
- Provide maximum safe operating conditions (winds, waves) for project managers to make informed decisions on when to bring floating equipment into port
- Protection of marine resources

Crane Barge Moorings: The safe mooring of floating equipment in close proximity to the shoreline and reefs presented challenges for the marine construction operations. Statistical wave/wind data and tidal current data were used to provide design conditions for the mooring of the crane barge coupled with a supply barge fully loaded with boulders. Multiple conditions of waves, winds and currents were simulated to provide design conditions for the system. While placing boulders from floating equipment was not possible in wave conditions greater than 3 to 4 feet in height, construction managers needed the option to suspend operations temporarily without the need to demobilize equipment to safe port at considerable expense in towing costs and delays in the construction schedule.

A dynamic mooring analysis was conducted to determine mooring forces. A system of pile anchors placed in the 50-foot buffer was selected as the anchoring system as opposed to conventional anchors. Steel H-piles were designed for the calculated mooring loads. The use of pile anchors avoids the potential for dragging anchors, and negates the need for a separate anchor handling barge. In addition, the system provided a stable, stiff anchoring system for precise positioning of boulder placement. However, the placement of anchors requires careful planning including review/approval by the construction managers as well as superintendents to ensure crane reach for all reef placement areas. The pile anchor locations were established to provide continuous coverage at optimized space intervals to allow for the barge system to winch itself with deck-mounted winches to the appropriate location without tug assistance, and to adjust the heading for sea conditions. Refer to Figure 6.

Figure 6: Crane barge mooring configuration.



Steel cables are typically used for the winch lines of a barge mooring system. However, floating lines with equivalent strength of the steel cable were utilized by conventional deck winches. The floating lines minimized the risk of cable-dragging in close proximity to reef edges. In addition, all barge towing operations used floating lines exclusively.

Single Point Mooring (SPM): The SPM was placed at a convenient location to both reef construction sites utilizing the LADS data. Placing the SPM in 70 feet of water was chosen to avoid wave shoaling effects and to be in between the second and third reefs. Towed underwater video mapping was conducted to confirm adequate sandy area for anchors and chain. Similar to the crane barge, a dynamic mooring analysis was conducted based on combinations of wave, wind and current loads for the design loading of a fully loaded boulder supply barge. The SPM was designed for wave heights up to 8 feet, giving the construction managers flexibility in planning for various sea state conditions.

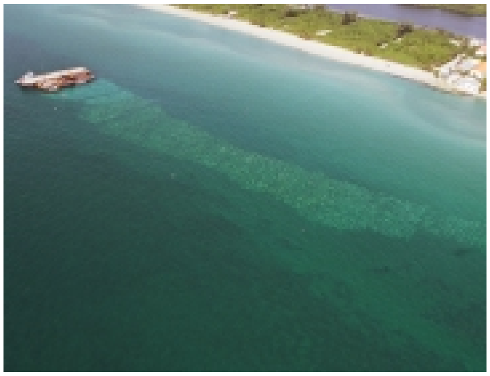
Rock Source

The limestone boulders in the specified size range are difficult to find in large quantities in South Florida. Sourcing 66,000 tons of boulders from quarries would have required over 3,000 truck loads of boulders to be staged at a waterfront site, then loaded onto barges for transport to the placement sites offshore. There were no convenient staging areas close to the construction areas, and this upland source of boulders would have required double-handling of the boulders. The expansion of the port facilities in Freeport on Grand Bahama Island presented an ideal opportunity to barge boulders directly to the reef sites without any upland staging area or double-handling of materials. Most of the boulders had been quarried during aggregate production, and a temporary barge loading area was established in the Bahamian port. Several initial loads of rock contained boulders which exceeded the 4 to 6 foot (nominal) size range. Though the biologists at the regulatory and resource agencies did not regard the oversized boulders as problematic and no permit violations were issued, the contractor's quality control program was refined to ensure that the remaining boulders conformed with the nominal specifications.

Precise Positioning

The construction specifications required precise placement of boulders to provide a single layer of boulders. Furthermore, precise positioning was required due to the complex geometry of the reef sites and proximity of marine resources. A system of Differential GPS (DGPS) receivers was used to provide the heading of the barge and positioning of the crane boom in real time. All of the receivers were interfaced with marine construction positioning software operating on computers on aboard the crane barge. CAD files from the reef construction plans were input directly into the positioning software to form a "honeycomb" template for the crane operator to place each boulder in a planned location. A computer located in the crane cab enabled the crane operator to verify the location of the crane boom and barge relative to the placement area. Once a boulder was placed, the crane operator marked the position. This technology allowed construction to progress on a 24/7 basis. The positioning equipment also assisted the superintendent with planning the sequence of construction and optimizing each barge move. The equipment provided sub-meter positioning accuracy in real time, and also produced as-built surveys as the construction progressed. Quality control diving operations were still required to ensure the continuous layer due to the boulder size variability and dynamic motion of the crane barge system.

Figure 7: Completed artificial reef configuration.



CONCLUSIONS

The engineered approach to this complex marine construction ensured that the Broward County Segment III Beach Restoration Project mitigation was completed on schedule, on budget (with no change orders), and most importantly with no impacts to marine resources. The pre-construction underwater video mapping confirmed reef placement areas and protective buffers. Mooring designs provided safe mooring systems for floating equipment utilizing coastal engineering analysis results. Precise positioning of the crane boom provided accurate placement of boulders within complex geometrical templates.

The resulting reef construction has produced immediate mitigation results, with juvenile fish and other marine resources that recruited shortly after boulder placement. The mitigation was also completed prior to beach construction, allowing for the transplantation of coral resources from the predicted nearshore impact areas.